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Biological and Chemical Composition of Boston Harbor, USA

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As part of a planning study of improvements to the navigation channels in Boston Harbor, Massachusetts (USA) biological and chemical composition were determined. During 1985 and 1986, sampling of the sediments and water column took place to understand existing conditions. These sampling efforts involved 21 sediment chemistry stations, 13 benthic infaunal stations, 6 otter trawl and gill net stations. The chemical determinations show high levels of contaminations in the inner channels. The benthic organisms react to this substrate chemical stress and a seasonal oxygen depletion with episodes of tolerance and defaunation. The finfish species follow a similar pattern as the infaunal community.

The biological and chemical composition of various sections of Federal navigation channels in Boston Harbor, Massachusetts (Fig. 1), were quantified to fulfil regulations in assembling an Environmental Assessment of a proposed Federal improvement dredging project. Recent investigations of the ecological status of Boston Harbor (NOAA, 1987; MDWPC, 1986; Boehm *et al.*, 1984; Sasaki Associates, 1983) have found that sections of the system are contaminated with heavy metals and organic contaminants and supports biota that exhibit physiological stress in the form of disease and histopathological disorders.

Adequate prediction of the potential impacts associated with a proposed deepening of sections of the Federal navigation channel require quantification of sediment contaminant levels, knowledge of the dominant benthic species and a characterization of fish movement throughout the harbour. In 1985–1986 sediment chemical determinations were obtained at 21 stations in Boston Harbor. Benthic populations were sampled at 13 stations (4 replicates per station) in July and November 1986 and fisheries sampling was conducted at 6 stations (Fig. 1). This study was initiated to

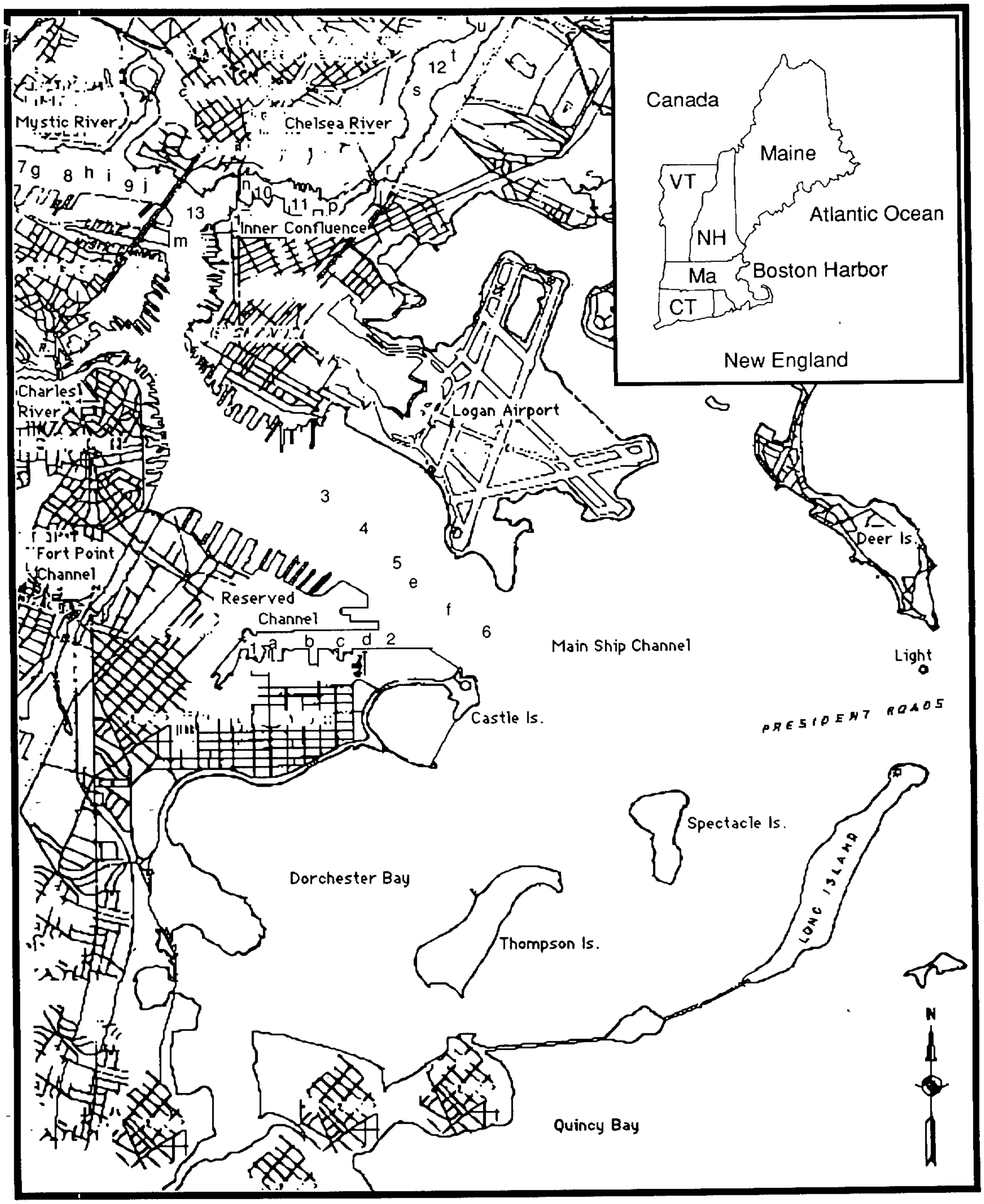

Fig. 1 Station locations. Chemical stations a–u. Biological stations 1–13.

assist in the impact prediction of a proposed improvement dredging project. The study design affords a general overview of the dynamic ecology of the harbour. The seasonal biological data reveal the common New England trend of warm weather hypoxia creating a defaunation or 'August effect' (D. Rhoads, pers. comm.).

Materials and Methods

Chemical

The physical and chemical characteristic of the sediments were analysed by the New England Division Laboratory of the Corps of Engineers using methods conforming to procedures (i.e. accuracy and precision) described by the US EPA (Plumb, 1981). Concurrent analyses of standard reference materials from the United States National Bureau of Standards and from Environment Canada indicated that all laboratory analyses during this effort were in control. Twenty-one stations were sampled by benthic grab and core in the navigation channels of Boston Harbor. Parameters measured include grain size, trace metals and some organic constituents in the sediments. The physical grain size determinations were by dry volume. Trace metals were analysed by using acid digestion and flame atomic absorption spectrophotometry. Arsenic analysis was performed by acid digestion and gaseous anhydride atomic absorption spectrophotometry. Mercury analysis involved acid digestion and cold vapor atomic adsorption spectrophotometry.

Oil and grease measurements were made from freon extraction and infrared spectrophotometry. Carbon, hydrogen, and nitrogen analyses used a combustion technique with an autoanalyser. PCB (Polychlorinated Biphenyl) compounds and DDT (Dichloro-diphenyl-trichloroethane) concentrations were analysed with hexane extraction and electron capture gas chromatography.

Each of the 21 sediment sampling stations were analysed for dominant soil classification, grain size, liquid and plastic limits, specific gravity and percent of solids, pH, volatile solids, chemical oxygen demand, oil and grease, mercury (Hg), lead (Pb), zinc (Zn), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), beryllium (Be), nickel (Ni), silver (Ag), manganese (Mn), vanadium (V), % carbon, % hydrogen, % nitrogen, DDT, and PCB.

Biological

Based on previous efforts in Boston Harbor, a sample size of 13 stations was found by statistical procedures to be adequate to detect a change (p. 263 in Sokal & Rohlf, 1981) in the benthic populations. The stations were located using a random number generator. Four replicate 0.04 m^2 Van Veen grabs were obtained at each station during two seasons (July and November). Each sample was observed undisturbed for grain size category, biogenic mixing depth, presence of epifauna or tubes, presence of oils and hydrogen sulphide (H_2S) odours. On board, samples were gently screened through a 0.5 mm sieve, stained with Rose Bengal and preserved in a 10% buffered formalin and seawater solution. Benthic organisms were identified to species level. These data are available upon request in the National Oceanic Data Center identification codes format.

TABLE 1
Sediment chemistry (1986).

	Mystic River n=4		Chelsea River n=8		Confluence of Mystic and Chelsea Rivers n=3	
% Fines	76.3	(29.0)	55.00	(20.0)	46.7	(29.5)
% Volatile solids	6.48	(5.48)	4.33	(1.33)	4.2	(2.5)
Oil and grease	2663	(2530)	2500	(1642.3)	843.3	(747.4)
Hg	0.68	(0.5)	0.72	(0.3)	0.8	(0.2)
Pb	168	(140)	166.6	(71.6)	197.7	(68.9)
Zn	215	(163)	176.5	(51.4)	201.7	(50.9)
As	14.9	(12.0)	6.7	(1.2)	6.5	(2.6)
Ba	870.0	(289.6)	1197.5	(378.6)	783.3	(165.0)
Cd	3.25	(0.5)	3.6	(0.5)	3.3	(0.6)
Cr	84.0	(66.4)	133.0	(37.5)	94.0	(44.8)
Cu	101.0	(85.6)	72.4	(30.4)	97.0	(54.4)
Ni	41.0	(23.4)	43.5	(16.8)	41.3	(21.2)
V	185.0	(101.2)	<100	(0)	<100	(0)
PCB	3.0	(n=1)	0.24	(n=1)	0.17	(n=1)

Mean (Standard Deviation).
All numbers in ppm, except for % fines and % volatile solids.

General water chemistry determinations were made during each day of sampling at various tidal quarters throughout the harbour. These determinations included a temperature (°C) and salinity (‰) profile at 1 m intervals using a YSI Model 33 Salinometer, surface (0.3 m) dissolved oxygen (ppm) using a modified Winkler Titration, secchi disc depth and general weather characterization.

Finfish were sampled using surface and bottom variable mesh (15 cm–2 cm) gill nets (approximately 2.5×70 m) with paired deployments and a 6 m otter trawl where possible. Rough bottom topography restricted trawling to the Mystic River (Fig. 1) and heavy ship traffic destroyed some of the gill nets. Sampling for finfish was, therefore, opportunistic for site and duration, with a total of 9 5 min. trawls in July, 4 in November, and 24 6 h gill net sets in each season.

Results

Chemical

Tables 1 and 2 summarize the results of sediment chemical analyses (mean and standard deviation) on a regional basis throughout the harbour. The following text references to low, moderate, or high concentrations are based on Massachusetts state guidelines as described in MWRC (1978) and listed in Table 3, with category 1 representing a low contaminant level and category 3 a high level.

The Mystic River sediments are predominantly fine grained organic clay materials in the western reach and pristine clay and clayey sand toward the eastern sector. High levels of PCB, volatile solids, lead, arsenic, zinc, and vanadium, and moderate levels of oil and grease, mercury, copper, chromium, and nickel are present in the western fine grained materials. The eastern section of the channel is relatively pristine clay with moderate levels of mercury, and oil and grease at the eastern most station. The mean concentration of samples (n=4) in the Mystic River (Table 1) characterized the region as having high concentrations of vanadium (185 ppm) and PCB (3.0 ppm, n=1). Moderate levels of percent volatile solids (6.48%), mercury (0.68 ppm), lead (168

TABLE 2
Sediment chemsitry (1986).

	Reserved Channel n=4		Main ship Channel n=2	
% Fines	81.8	(15.4)	86.5	(2.1)
% Volatile solids	5.4	(2.6)	7.6	(0.9)
Oil and grease	2700	(2685)	1350.0	(70.7)
Hg	1.0	(0.6)	0.46	(0.03)
Pb	130.0	(61.8)	111.5	(14.8)
Zn	178.8	(60.1)	139.5	(16.3)
As	7.1	(1.4)	5.2	(0.1)
Ba	852.5	(238.0)	810.0	(42.4)
Cd	3.25	(0.5)	4.0	(0.0)
Cr	117.5	(47.0)	116.0	(21.2)
Cu	100.3	(43.0)	81.0	(4.2)
Ni	47.0	(11.6)	41.0	(1.4)
V	<100	(0.0)	<100	(0.0)
PCB	0.77	(n=1)	not analysed	

Mean (Standard Deviation).
All numbers in ppm, except for % fines and % volatile solids.

TABLE 3
Massachusetts classification of dredged material (MWRC, 1978).

	Category 1 (ppm)	Category 2 (ppm)	Category 3 (ppm)
As	<10	10–20	>20
Cd	<5	5–10	>10
Cr	<100	100–300	>300
Cu	<200	200–400	>400
Pb	<100	100–200	>200
Hg	<0.5	0.5–1.5	>1.5
Ni	<50	50–100	>100
PCB	<0.5	0.5–1.0	>1.0
V	<75	75–125	>125
Zn	<200	200–400	>400
Physical characteristics			
	Type A	Type B	Type C
% Silt-Clay	<60	60–90	>90
% Water	<40	40–60	>60
% Volatile solids	<5	5–10	>10
% Oil and grease	<0.5	0.5–1.0	>1.0

ppm), zinc (215 ppm), and arsenic (14.9 ppm) were also present.

The Chelsea River sediments contained elevated levels of contaminants (lead) at only two of the eight stations sampled. In general, moderate levels of oil and grease, mercury, zinc, lead, chromium, and copper were found at some stations. All other contaminants were low or below detectable concentrations. The average (n=8) concentration (Table 1) characterize the sediments of this region as having moderate levels of mercury (0.72 ppm), lead (166.6 ppm), and chromium (133.0 ppm).

The sediment samples of the inner confluence area of Boston Harbor have low levels of most contaminants. High lead concentrations were present at one station, moderate mercury, chromium, lead, zinc, or nickel were present at others. The averaged concentrations (n=3) exhibited moderate levels of mercury (0.8 ppm), lead (197.7 ppm), and zinc (201.7 ppm). Other contaminants were present in low levels.

The Reserved Channel sediments were predominantly organic clay (0–18 cm) over lean clay (18–23 cm). The average grain size decreases from the innermost stations to the outer stations. Lead was present in high levels (221 ppm) at the western station and in moderate concentrations at the other stations (105–109 ppm). Oil and grease, mercury, zinc, chromium, and nickel were present in moderate concentrations in various replicates. The averaged concentrations (n=4) characterized the region as having moderate levels of volatile solids (5.4%), mercury (1.0), lead (130.0 ppm), chromium (117.5 ppm), and PCB (0.77 ppm, n=1) (Table 2).

The Main Ship Channel region of the harbour had no high levels of contaminants in individual sediment samples, but had moderate levels of volatile solids, lead, and chromium. The averaged (n=2) concentrations (Table 2) of these samples characterize the sediments of the region as having moderate level of volatile solids (7.6%), lead (111.5 ppm), and chromium (11.60 ppm).

Biological

Benthic samples (n=50) from Boston Harbor in July contained an average of 4,089.0 (S.D.=5115.9) organisms m^{-2} from 9.5 (S.D.=8.6) species. The dominant organisms are the polychaetes *Capitella* spp. (44.1%, S.D.=35.5), *Polydora aggregata* (13.7%, S.D.=12.0), and *P. ligni* (12.9%, S.D.=11.0). Between July and November, a statistically significant ($p<0.001$) reduction occurs in benthic population densities (Ni) and diversity (Ns) (single classification ANOVA). The November population contained an average of 546.6 (S.D.=1044.4) organisms m^{-2} from an average of 1.8 (S.D.=2.7) species. The dominant organisms were the polychaetes *Streblospio benedicti* (22.8%, S.D.=18.7), *P. ligni* (19.8%, S.D.=28.3), and the amphipod crustacean *Ampelisca abdita* (13.3%, S.D.=16.3).

Finfish samples using gill nets were obtained in the Mystic River during a 24 sampling hour effort on two different sampling days (one in July and one in November). The only Mystic River finfish species recovered in the July and November gillnet deployments was the rainbow smelt *Osmerus mordax* (green crabs *Carcinus maenas* were also recovered).

Finfish samples using 10 m Otter Trawls were taken in the Mystic River 9 times (5 min. tows at 4 kts) in July and 4 times in November. No species were collected in July except for an occasional starfish (*Asterias vulgaris*). In November winter flounder, *Pseudopleuronectes americanus* dominated the trawl catches. The pooled sample contained 443 winter flounder (58.2% male) averaging 0.59 kg (S.D.=3.51) with an average individual weight of 0.014 kg. Qualitative observations of their stomach contents revealed crustacean and polychaete prey items. The windowpane flounder *Scopthalmus aquosus* was the next dominant species with a pooled density of 23 organisms averaging 8.87 cm (S.D.=4.19) and individual weight calculated as 0.018 kg. Fourteen rainbow smelt *Osmerus mordax* averaged 13.1 cm (S.D.=3.95); twelve blueback herring *Alosa aestivalis* averaged 11.2 cm (S.D.=1.67); seven Atlantic silverside *Menidia menidia* averaged 11.1 cm (S.D.=4.20); and two longhorn sculpin *Myoxocephalus octodecempinosus* averaged 8.3 cm (S.D.=0.42). Additionally, shore shrimp (*Crangon septemspinosa*) were estimated at 5796 individuals weighing 3.62 kg (total wet wt) and 72 green crabs *Carcinus maenas* averaging 4.54 cm (S.D.=1.12) and weighing approximately 0.026 kg each were recovered.

Gillnet finfish samples in the Chelsea River were obtained during a 48 hour sampling effort on two different sampling days (one in July and one in November). The dominant finfish species in July (26 net hours) was rainbow smelt *O. mordax*, four of which averaged 16.0 cm (S.D.=1.1). Also present were an alewife *A. pseudoharengus* (26.5 cm), a menhaden *Brevoortia tyrannus* (23.0 cm), a spider crab *Libinia emarginata* (6.7 cm), and four green crabs *C. meanas* (6.3 cm). The 12 sample hour gillnet deployment in November did not capture any organisms.

Finfish samples in the Main Ship Channel area were obtained during a 72 sampling hour effort on four different sampling days (two in July and two in November). The dominant finfish species was winter flounder, *Pseudopleuronectes americanus* in all samples.

Sampling at outer Main Ship Channel sites (stations 5 and 6) obtained more species and individuals than inner Main Ship Channel sites (Stations 3 and 4) in both seasons. In addition to winter flounder, the July sampling obtained rainbow smelt *O. mordax*, lobster *Homarus americanus*, alewife *A. pseudoharengus*, windowpane flounder *Scopthalmus aquosus*, Atlantic menhaden *Brevoortia tyrannus*, and Jonah crab *Cancer borealis*. The November sampling revealed the same *P. americanus* dominance and rainbow smelt *O. mordax*, windowpane flounder *Scopthalmus aquosus*, tomcod *Microgadus tomcod*, Atlantic mackerel *Scomber scombrus*, blueback herring *A. aestivalis*, Longhorn sculpin *Myoxocephalus octodecemspinosus*, Jonah crab *C. borealis*, and green crabs *C. maenas*.

Fisheries resources of the inner and outer harbour have been inventoried by previous studies including the MES (1970–1977) and Haedrich & Haedrich (1974) studies that have developed information in the Lower Mystic River. Data in the Outer Harbour was developed by Jerome *et al.* (1966), Chesmore *et al.* (1971), and Iwanowicz *et al.* (1973). The studies on the Lower Mystic River were concentrated in the area between Amelia Earhart Dam and the Mystic River (Tobin) Bridge. These and Haedrich & Haedrich (1974) reported seasonal species composition similar to this sampling effort. Winter flounder, smelt and alewives are found in the river throughout the year and are, therefore, considered residents. Ocean pout and blueback herring are summer residents, whereas sea herring is considered a winter resident. Haedrich & Haedrich (1974) also found the major food sources are generally as described for the species elsewhere (NMFS, 1984 and NOAA, 1987). *P. americanus* feeds mainly on the polychaete *Capitella capitata*, amphipods, and soft shell clams *Mya arenaria*; smelt primarily on sand shrimp *C. septempinosa* and other small crustaceans; and alewives and herring on zooplankton.

Discussion

Chemical determinations averaged for selected areas of the Federal navigational channels in Boston Harbor depict the substrate as having low to moderate contamination except for high levels of PCB, in the Mystic River. Individual samples contained high levels of Pb, Zn, V, and As in the western reaches of the Mystic River; some high lead concentrations in the Chelsea River, Inner Confluence area, and Reserved Channel; and low to moderate contaminant levels throughout the rest of the samples. The toxicity and availability of these contaminants and polycyclic aromatic hydrocarbons (Clark & Gibson, 1987) through the trophic system is scheduled to be analysed by standard bioassay and bioaccumulation testing (EPA/CE, 1977) in 1990.

Concurrent with the environmental stresses of the sediment contamination is a seasonal depletion of dissolved oxygen with August bottom concentrations falling as low as 1.3 ppm (MDWPC, 1985, 1986, 1987). The low dissolved oxygen levels are temperature dependent and affected by thermal stratification of the water column. A large primary sewage treatment plant effluent discharges into the Boston Harbor ecosystem and presumably, along with riverine sources, maintains a constant input of material with a high chemical oxygen demand and contaminant influx. Several years of data obtained by the MDWPC show this hypoxic cycle as summarized in Table 4. Recent studies of the environmental quality of the harbour, relative to loading of elements and organics in the system, have characterized the area as ecologically degraded (Table 5). Toxicity tests were conducted in December 1987 (Jop, 1988) showing the existing effluent to be toxic using the following tests: *Arbacia punctulata* fertilization (55.7% and 79.9% unfertilized in 100% effluent); LC_{50} of *Cyprinodon variegatus* at 70.7% and 69.6% effluent; LC_{50} of *Mysidopsis bahia* at 92.7% and 67.0% effluent.

The benthic organisms react to the substrate chemical stresses and seasonal oxygen depletion with episodes of tolerance and defaunation. The harbour benthic faunal assemblages have been studied in the lower Mystic River and Inner Harbour areas (Stewart, 1968; MES, 1970–1977). The communities are primarily made up of opportunistic deposit feeders such as polychaetes and amphipods which are associ-

TABLE 4
Dissolved Oxygen Concentration (mg l^{-1}) for Massachusetts Division of Water Pollution Control Survey Stations BH01 (Mystic River) and BH04 (Charles River) bottom samples in water column (MDWPC 1987 & MDWPC 1986).

Date	Mystic River (BH01) (mg l^{-1})	Charles River (BH04) (mg l^{-1})
10 June 1986	3.3	4.5
11 June 1986	3.5	2.5
8 July 1986	3.8	4.5
9 July 1986	4.7	4.8
5 Aug. 1986	3.7	5.3
6 Aug. 1986	4.7	1.1
9 Sept. 1986	5.28	5.09
10 June 1985	5.8	5.1
12 June 1985	4.6	4.1
30 July 1985	5.4	2.9
31 July 1985	5.1	4.8
20 Aug. 1985	5.7	–
21 Aug. 1985	5.2	–
7 Oct. 1985	4.7	4.2
8 Oct. 1985	5.1	3.1

TABLE 5
The present system loading (O'Brien, 1988).

Constituent	Average loading in kg day^{-1}
As	2.72 (0.86)
Cd	3.22 (1.22)
Cr	34.38 (13.38)
Cu	156.49 (46.72)
Cy	24.45 (6.31)
Pb	22.63 (9.89)
Hg	1.86 (2.36)
Ni	29.94 (13.38)
PCB	<1.0 ng l^{-1}
TSS	202 000
BOD	227 000
Phenol	24.7 (12.3)
2,4,5-Trichlorophenol	158.3 (43.5)
Dimethyl phthalate	31.6 (8.8)
Tetrachloroethene	21.5 (12.5)
Methylene chloride	47.5 (34.2)
Benzene	5.7 (1.0)
Toluene	27.6 (17.3)
Domestic wastewater flow	4.66×10^8

ated with the harbour's organic rich silts. Previous studies have indicated that the lower Mystic River is dominated by the polychaete *Capitella* sp. (MES, 1977) and are in good agreement with the 1986 sampling programme reported here. The harbour is inherently stressful to benthic populations which respond to these stresses by niche exploitation selection of specialized species for dominance. Those organisms that are tolerant of low levels of dissolved oxygen, on a cyclic basis, survive. Where the synergistic total of all environmental stresses defaunate the substrate (eliminating non-mobile bottom dwelling organisms), the tolerant species colonize the vacant substrate as stresses decline to tolerable levels usually associated with seasonal temperature cycles. It is this type of benthic community, in dynamic equilibrium, that is present in Boston Harbor (dynamic in response to environmental stresses and equilibrated to cycles of defaunation) (D. Rhoads, pers. comm.). This seasonal reduction in benthic productivity is not uncommon in urban estuaries where the cumulative effects of high organic load, vessel wakes, increasing water temperature, reduced wind mixing, and increased water column stratification combine with microbial activities that peak in late summer to reduce water column dissolved oxygen levels. The dissolved oxygen stress is often severe enough to eliminate non-motile benthic populations or drastically reduce their densities.

Those areas that are highly contaminated represent a potential pathway for pollutants (e.g. Hg, Cd, Cr, PAH, and PCB) to accumulate in higher trophic levels. Recent investigations in the Quincy Bay area of Boston Harbor (Metcalf & Eddy, 1988) have reported elevated PCB tissue residue in lobster, *Homarus americanus,* muscle ranging 0.203–0.272 $\mu g\ g^{-1}$ (wet wt) and hepatopancreas 22.8–61.8 $\mu g\ g^{-1}$ (wet wt). This study also reported winter flounder, *Pseudopleuronectes americanus* as having PCB ranging 0.061–0.747 $\mu g\ g^{-1}$ (wet wt); chlordanes 0.000–0.030 $\mu g\ g^{-1}$ (wet wt); and DDT 0.002–0.026 $\mu g\ g^{-1}$ (wet wt). The short lived life cycle of the pioneering type organisms responding to the 'August Effect' may represent a trophic buffer against excessive bioaccumulation of contaminants in the benthos. These short lived populations have limited time to bioaccumulate, but represent high densities of prey items for foraging juveniles and adults using the estuary.

The polychaetes *C. capitata* and *S. benedicti* are the dominant benthic organisms present in the navigation channel. Both of these species are tolerant of physical and chemical stresses that are characteristic of urban harbours such as Boston. Each of these species are 'r–strategists', i.e. species whose life history is characterized by small body size, short generation times, and high reproduction (Grassle & Grassle, 1974; Levin, 1986). *C. capitata* has shown generation times as short as 3 weeks (Tenore & Chesney, 1985). These life history attributes allow the proliferation of this species within the project area on a cyclic basis. High densities of *C. capitata* were found in July, but not in November. The high suspended organic load present in Boston Harbor facilitates water column oxygen depletion as the inner harbour warms and stratifies (i.e. an 'August Effect') in late summer. If this depletion is severe enough, in combination with other environmental stresses, it may defaunate the substrate. Visual observations of many Mystic River samples revealed an oily sheen and strong petroleum or H_2S odours. Chemical determinations measured moderate oil and grease levels. Those project areas azoic in both sampling periods may have a sufficient additional stress of hydrogen sulphide or petroleum compounds accumulating in the substrate that is intolerable to even these species (James & Gibson, 1980). Winter mixing and cooling allows the r–strategists to re-establish their densities. This cyclic proliferation and die-off keeps the benthic population in a state of dynamic equilibrium favouring species that are not long-lived. A similar phenomenon occurred in New Haven, Connecticut, another temperate New England harbour (NAI, 1985). The total of environmental stresses in this harbour maintained a 'pioneering' type of benthic community (i.e. pioneering sere). As pollution abatement efforts proceeded, including a change from primary to secondary sewage treatment, the benthos of New Haven Harbor began to not experience an annual die-off. This ecological improvement caused a sere shift favouring more long-lived or a 'mature' community (mature sere) to evolve, e.g. from dominance of capitellids to amphipods (NAI, 1985). The proposed switch from primary to secondary sewage treatment for Boston Harbor has the potential to parallel the New Haven Harbor 'sere shift'. A complication of this phenomenon is that the longer lived, mature communities have the potential to bioaccumulate sediment contaminants to a higher concentration simply because they are associated with the substrate for a longer time. This study identified high densities of juvenile winter flounder feeding in the Mystic River, the region of highest average chemical contamination. Since the sediment chemistry will be proportional to biotic contaminant uptake, the Mystic River area of Boston Harbor would potentially be a particularly contaminated pathway if a sere shift occurs.

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